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REPORT OF THE WORKSHOP ON ANTARCTIC AUTONOMOUS SCIENTIFIC VEHICLES AND TRAVERSES

February 14 and 15, 2001

National Geographic Society, Washington DC

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EXECUTIVE SUMMARY

The workshop on Antarctic Autonomous Scientific Vehicles and Traverses met at the National Geographic Society on February 14 and 15 to discuss scientific objectives and benefits of the use of rovers such as being developed for use in planetary exploration. The participants enthusiastically viewed rovers as being uniquely valuable for such tasks as data taking on tedious or repetitive routes, traverses in polar night, difficult or hazardous routes, extremely remote regions, routes requiring only simple instrumentation, traverses that must be conducted at low speed, augments of manned traverses, and scientific procedures not compatible with human presence or combustion engines. The workshop has concluded that instrumented autonomous vehicles, of the type being developed for planetary exploration, have the potential to contribute significantly to the way science in conducted in Antarctica while also aiding planetary technology development, and engaging the public's interest. Specific objectives can be supported in understanding ice sheet mass balance, sea ice heat and momentum exchange, and surface air chemistry processes. There are issues of rover capability and scientific instrumentation that require additional development, but even in the immediate future there are useful implementations which would serve to initiate this approach. We recommend that this general concept be pursued further in the scientific and autonomy communities so that an international, multi-agency program can be generated to address technology development and Earth science.

THE WORKSHOP

On February 14 and 15, 2001, a workshop was held at the National Geographic Society buildings in Washington DC to examine the scientific benefits of deploying instrumented autonomous vehicles in Antarctica. Represented at the meeting were US, British, French, and German participants; from the US there were members of the academic scientific and technical communities, NASA centers, and the National Science Foundation. The participants list is in Appendix A. Workshop discussions covered the state of development of autonomous vehicles, the scientific objectives, benefits and limitations of ongoing Antarctic traverse science, the scientific opportunities and requirements for autonomous traverses, the prospective scientific instrumentation for autonomous traverses, the challenges provided to the technical community by both the Antarctic environment and the science requirements, and the tasks to be addressed to develop a scientifically meaningful international multi-agency program in autonomous traverses.

BACKGROUND: THE OPPORTUNITY

The in-situ exploration phase of solar system exploration has begun and will continue and become increasingly sophisticated and capable. In most cases the great distances involved and occasional occlusion of the communications pathways imposes a requirement for at least partial autonomy. As a consequence, autonomous exploration vehicles are in vigorous development by space agencies with Mars as the immediate objective. The Mars rovers being developed are long-range, solar powered vehicles with 4 or more spherical tires of radius 1-2 m. The mean Mars surface temperature is about –60°C, and the windforce is negligible due to the very small atmospheric density. These environmental conditions are reasonably well presented by the south polar plateau, and the vehicles being designed appear to be well suited to ice sheet travel. The testing of autonomous long-range planetary exploration systems in Antarctica can logically be planned as a long-range traverse similar to those performed for ice sheet science. Clearly, the plans to test these vehicles serve to generate the extremely interesting possibility of a partnership between planetary technology development and Earth science. A key issue is whether there is a clear benefit to Earth science from this situation, and this workshop has the objective of exploring that benefit.

TRAVERSE PRACTICE TODAY

Ice sheet traverses were an essential element of early ice sheet exploration and study in Antarctica and Greenland, and the overland traverse is still today used in camp emplacement by several national Antarctic programs. Scientific traverses have recently resumed in Antarctica, conducted principally as part of the 15 nation International Trans-Antarctic Scientific Expeditions (ITASE; see http://www.antcrc.utas.edu.au/scar/itase/itase.html) program which is focused on paleoclimate studies covering the past 200 years. The ITASE program has been strikingly successful through addressing scientific objectives in paleoclimatology, geophysics, surface glaciology, remote sensing and meteorology.

SCIENCE OPPORTUNITIES PROVIDED BY AUTONOMOUS ROVERS

The critical issue is whether there are significant science tasks for which autonomous rovers are uniquely suited, tasks done significantly more poorly or at greater cost with other means.

Autonomous Rover Science Tasks.

--Detailed and Tedious Routes. Mapping routes such as “mowing the lawn” for detailed information in a region are notoriously difficult for operator-controlled systems due to loss of concentration and impatience. Acquiring dense observations to describe a transition zone from wet to frozen glacier or ice stream bed, for example, will call for such routes in remote areas, a good task for an autonomous rover.

--Polar Night. Numerous surface processes are thought to occur during the dark of polar winter, but current sampling is restricted to year-round coastal stations. Several winter processes are poorly understood, including timing, duration and magnitude of snow accumulation and grain-size modification. These can be addressed by a winter transect, as can the timing of appearance of chemical species and the onset of photochemistry as daylight comes to the ice sheet in spring.

--Difficult or Hazardous Routes. Medium and long-range traverses across sea ice are challenging by virtue of ridges and open-water areas, and a similar situation occurs in heavily crevassed areas of the ice sheet. Both of these regions are scientifically interesting.

--Extremely Remote and/or Inhospitable Routes. Some areas of East Antarctica and several mountainous areas and so remote that airborne support is logistically difficult, but they could be readily accessible to rovers.

--Routes Involving Simple Instrumentation. Acquisition of recent snow accumulation or topography change data for a region may be crucial to comparing data sets or to cal/val for a satellite data set, yet the mission cannot justify a full manned traverse, or the timing of the data need may be urgent.

--Instrumentation Requiring Slow Traverse Speed. Certain geophysical observables, e.g. magnetometer and gravimeter data, must be taken at the surface at a speed slower than aircraft speed; for these data sets a rover is ideal. In addition, the smaller mass of ferromagnetic materials and electronic activity of a rover traverse would benefit the magnetometer observations.

--Augments of Manned Scientific Traverses. Manned traverses are increasingly capable in scientific breadth, but they are inherently one-dimensional; the acquisition of a reduced set of data on tracks orthogonal to the manned traverse can provide 2-D statistics without impacting progress of the main traverse.

--Measurements Not Compatible with Presence of Humans or Combustion Engines. One aspect of the traditional traverse is the generation of pollutants by both the humans and the combustion engines involved. Only by carefully selecting for upwind conditions can the traverse sources be mitigated, and then only partially. A solar powered unmanned rover would present many orders of magnitude reduction in nearly all these pollutants, an essential situation in many chemical investigations.

CANDIDATE SCIENCE PROJECTS FOR AUTONOMOUS ROVERS

Ice Sheet Mass Balance.
Autonomous Rovers equipped with sounding radars can map snow accumulation, isochronous layer depths, ice thickness and subglacial topography and condition. Augmenting with shallow corers would allow determination of snow isotopic and chemical composition. Snow accumulation is required for computation of ice sheet mass balance, either by field measurements or numerical modeling. It is also one of the least explored components of the global hydrological cycle. Tracking of isochronous layers over large distances provides estimates of accumulation rate and deformation and can connect "calendars" at widely separated sites. Ice thickness is also a necessary component for ice sheet models and subglacial topography aids understanding of ice sheet flow. Also possible are evaluation of climate variability in time and space, detailed mapping of basal conditions in regions of transition, extension of accumulation statistics normal to major traverse lines, mapping of accumulation and isochron depths along ice divides and flow lines, and providing calibration/validation data for satellite data sets.

Heat and Momentum Exchanges Through Sea Ice.
Sea ice regions are characterized by large and variable fluxes of heat and mass between the atmosphere, ice and ocean mixed layer, and the sea ice field is difficult to map with traditional means due to its roughness and the occurrence of open water and thin ice areas. The air-sea-ice system is highly sensitive to climate change. A light-weight, buoyant rover such as has been described can accommodate this situation by taking Em induction or acoustical measurements of sea ice and snowcover thickness as well as surface temperatures, winds, and oceanic salinity over extensive traverses from near shore to the marginal zone through leads and polynyas.

Snow Surface Chemical Processes.
Chemical exchange between the atmosphere and snowpack is complex, and, because of the vast surface area of the polar ice sheets, can have a profound effect on trace components of the polar atmosphere and ice. These processes are particularly dynamic at the end of polar night. While chemical concentrations are miniscule, modern methods, especially in mass spectrometry, offer the prospect of monitoring these processes in situations in which the presence of humans and combustion engines cannot be tolerated, and during periods when field investigation by humans is impossible to support..

SCIENCE REQUIREMENTS ON MEAUREMENTS

The measurement system of rover and instrumentation will have science requirements placed on it depending on planned objectives. These requirements include accuracy and precision, spatial and temporal density, and stability of calibration. Setting of these requirements is on a case-by-case method, and, in many situations, a comparison across long time intervals is required for variables not well understood.

ROBOTIC CHALLENGES OF POLAR TRAVERSES

Robotic capabilities for Antarctic deployment must be addressed considering both science requirements and the environment. A preliminary examination suggests that significant issues will include the capability for traverses of about 100 days, capability to control position at the meter level, crevasse detection and avoidance, 24 hour per day operations, route selection and decision making, self-diagnosis and recovery, power, wind, blowing snow, deep snow, sastrugi, operations with optical systems pointed at the sun, communications, and articulating , self-stowing solar array(s).

A PHASED DEVELOPMENT APPROACH

In the discussions of scientific objectives it is clear that the overall requirements for autonomous polar rovers involves extensive capability in mobility, power generation, and scientific instrumentation. There may also be challenging requirements in areas such as communications. In mobility, there is a significant difference between operations on the polar plateau in summer and on the coastal ice shelves, where temperatures are relatively mild, winds less intense and solar power readily available, compared to winter when weather conditions and power generation are much more difficult. There are simple science instruments such as magnetometers, weather sensors. GPS receivers and sounding radars, which can be implemented immediately; more complex measurement systems such as drills with chemical sensors for ice characterization at depth, would require significant engineering development. As a consequence of this range of capability, a phased approach seems prudent. In such an approach an early project would address simple instruments on the plateau in summer, and later projects would add to the engineering requirements in vehicle and science capability. And, of course, at least one initial traverse is needed as a system and concept test. We suggest below a logical sequence for the first two or three traverses.

SOUNDING RADAR, A PROSPECTIVE INSTRUMENT FOR ICE SHEET MEASUREMENTS

Sounding radar is a candidate instrument for ice sheet deployment on autonomous Antarctic rovers. Suitably designed radars are capable of several useful ice sheet observations including accumulation, ice thickness, isochron depth, basal condition (wet or frozen), basal roughness and bottom crevassing. Recent technical advances in cell-phone components have contributed greatly to reducing the size and power consumption of radar components, and this directly benefits autonomous vehicle deployment. A valuable radar system can be implemented with operating frequency selected from a range of 50 to 1000 MHz such that the higher frequencies are used for near-surface accumulation and the lower frequencies in isochron and basal observations. This configuration results, with off-the-shelf components, in a radar system of 20 kg mass and 50 Watts power; these numbers can be appreciably reduced with substitutions of low-power computing elements. An additional science benefit can be realized through a multi-rover multi-aperture multi-frequency multi-polarization radar to obtain fine resolution in isochron depth and basal condition. These radars generate moderate data, in the range of Gigabites per month, which would call for either good (but not intimidating) communications or reliable on-board storage.

MISSION SCENARIOS

There are numerous approaches to the general concept of robotic polar traverses:
--Mars-like, lightweight solar-powered ice sheet rovers deploying radars and miniaturized instruments such as low-power radars and magnetometers.
--Mars-like sea ice rovers with different instruments, designed with ship and air deployment and maintenance.
--An automated tractor towing sleds with automated instruments, tended on an as-needed basis by air.
--NOMAD-like rovers with on-board instrumentation, e.g. radars and magnetometers, with the possibility of adding more demanding devices, e.g. shallow corers. One possibility is to deploy NOMAD during the US ITASE traverse from Byrd Station to South Pole in 2002-2003. A simple experiment would be to collect navigation and shallow radar data along the route to be taken by the heavy vehicle traverse. This exercise would provide an opportunity for comparison. An alternative experiment would be use the rover to conduct short orthogonal transects to the main route, thereby extending the spatial coverage. In any case, in situ monitoring of rover performance can be conducted by ITASE personnel.

ON REFLECTION, IS THERE A WORTHWHILE JOB TO BE DONE?

In summing up our 2 days of work here there is a key question: Is there a worthwhile job to be done in advancing the development of scientific autonomous vehicle traverses in Antarctica? There are several categories of conclusions:

Science: Yes.
We have determined that the autonomous rover (similar to the version being developed for planetary exploration) can enhance current scientific programs and open new windows of study.

Technology: Yes.
The Antarctic autonomous rover poses a grand challenge to the autonomous vehicle community, and we perceive spin-off value in a number of areas.

Public Interest: Yes.
There is enormous potential in autonomous vehicles undertaking long and challenging traverses across the ice sheet. Optimizing public interest will of course place requirements on the rover implementation and development program, e.g., it would be desirable to deploy rovers in groups so that each rover can be observed by another. We do not see these requirements as constituting a significant obstacle.

HOW SHOULD WE PROCEED FROM HERE?

Summarize and Publicize our conclusions.

Continue to Communicate.

Expand the Partnership.

Work with Agencies for Programmatic Collaborations.

Gain International and Multidisciplinary Participation.
--Calibration and validation requirements from satellite programs in the near future, e.g. ICESat and Cryosat.
--Negotiate optimal role for SCAR

Advance Development Plan.
--Examine use of NOMAD in the short term for demonstration of autonomous rover capabilities.
--Consider comprehensive testing strategy; how can Greenland be used?

Initiate Proposal Generation.
NASA technology opportunities, especially in summer of 2001
NSF Polar Instrumentation in 2002

WHAT ARE THE SHORT-TERM PROJECT GOALS?

Examine upcoming proposal deadlines for opportunities in autonomous rovers.

Utilize publication opportunities in professional society publications (e.g., *Ice*).

Develop standard sets of slides, videos of NOMAD, and the like for public relations.

Use Existing Autonomous Resources to Test Basic Assumptions.
We should move to undertake a simple autonomous traverse using a system such as NOMAD (of Carnegie-Mellon University) to demonstrate basic navigation of a simple route, and other issues.

Discuss with NASA ICESat management on simple validation results for autonomous rovers. A simple job with which to initiate this activity would be a detailed topogaphy over some few kilometers within a few kilometers of McMurdo.

SUMMARY

This workshop has concluded that instrumented autonomous vehicles, of the type being developed for planetary exploration, have the potential to contribute significantly to the way science in conducted in Antarctica. Specific objectives can be supported in support of understanding ice sheet mass balance, sea ice heat and momentum exchange, surface air chemistry processes, and fine-scale geophysics. There are issues of rover capability and scientific instrumentation that require additional development, but even in the immediate future there are useful implementations which would serve to initiate this approach. We recommend that this general concept be examined by international science committees and funding agencies and pursued further in the scientific and autonomy communities so that an international, multi-agency program be generated to address technology development and Earth science. We also recommend that additional workshops be considered to develop a long-range strategy for coordinating relevant aspects of autonomous rover technology and polar science.

APPENDIX 1: PARTICIPANTS

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